Symposium in honor of

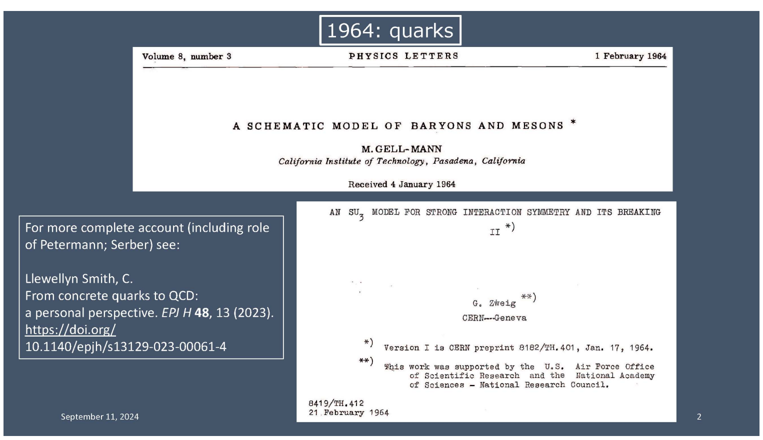
Professor Brian Foster

Oxford, September 11, 2024

Ladies and gentlemen, dear colleagues, dear Brian,

Slide 1[1]

Slide 2



In January 1964, when Brian turned 10, Murray Gell-Mann submitted his paper introducing quarks as the building blocks of hadrons.

[1] Slides are appended to this writeup

Quarks were very controversial not only at the time they were proposed but for years to follow. At the same time and independently the young CERN post-doc George Zweig introduced ‘aces’, similar to Gell-Mann’s quarks. His paper was rejected bij the journals he submitted it to, it never got beyond the status of CERN-TH preprint. On the slide I include a reference to a recent review of the history of the quark model (and beyond) in which also the original contributions of Petermann are acknowledged.

At the end of his article Gell-Mann writes: ‘It is fun to speculate about the way quarks would behave if they were physical particles of finite mass (instead of purely mathematical entities as they would be in the limit of infinite mass).’

The introduction of quarks was inspired by hadron spectra and in particular by supermultiplets of hadrons arranged according to their isospin and strangeness. These supermultiplets corresponded to 8, 10 dimensional irreducible representations of the group SU(3). And the quarks (and antiquarks) to the 3 dimensional fundamental representations of this group. They had fractional quantum numbers (in particular charge and baryon number) which explains the reluctance to accept them as real particles. The quark model led to an extensive experimental programme for studying hadron spectroscopy and dynamics.

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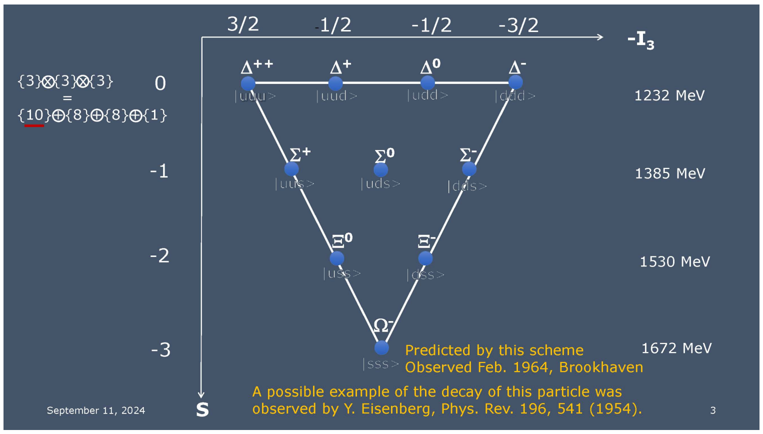
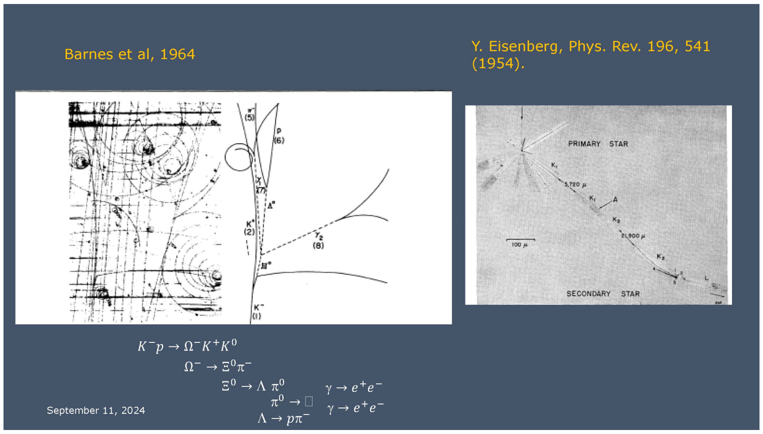


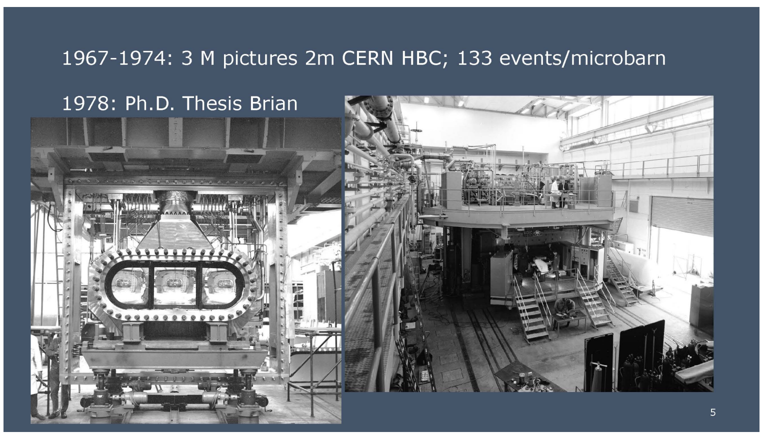
shows, as an example, the baryon decuplet, featuring the Ω^- strangeness minus three baryon discovered after the decuplet symmetry was proposed and in fact giving strong support to the quark model. The Ω^- was first observed in February 1964 in Brookhaven (**Slide 4, left**), but it was in fact probably observed a decade earlier in an emulsion stack exposed to cosmic rays at high altitude by a later ZEUS collaborator of ours, Yehuda Eisenberg.

Slide 4, right pays tribute to this observation.

Slide 5

In 1967 the first exposure of the CERN 2m hydrogen bubble chamber to a 4.2 GeV/c K^- beam took place. The last exposure took place





in 1974.

I remember being on shift during data taking, already as an undergraduate. The tasks we had to perform were not very complex. On samples of the film we had to count the number of incoming beam particles, the number should be around ten, and we had to count ionization bubbles along the minimum ionizing beam tracks. And when it turned out that something was not quite optimal, some tuning was necessary. I think we had command over the beam and when we had to tune it the expansions of the bubble chamber had to be brought out of phase with the beam pulses. In order for that to happen we had to phone the bubble chamber crew and say: 'voulez vous déphaser la chambre?'. It was my first French sentence after high school.

I also remember standing next to the bubble chamber during operation. The expansion went along with a loud bang and the flash of light showed the tracks in bright white and the rest of the chamber in blue. I don't know how accurate these memories are, I do suspect that standing next to the chamber must have been against the rules.

In total 3 million pictures were taken. The data sample corresponded to 133 events per microbarn. That was a large integrated luminosity for a bubble chamber experiment. Progress in our field is illustrated by the fact that this luminosity corresponds to 10 milliseconds of LHC running. The experiment was aimed at studying hadron resonances, their production and decay. The relevance of the experiment was clearly based on the quark-model and on the fact that the strong interactions were not well understood.

The experiment X42, performed by the Amsterdam-CERN-Nijmegen-Oxford collaboration, was Brian's thesis experiment. It was also my thesis experiment.

Brian completed his thesis in 1978, below is a quote from the paper based on his work, published in 1981 when Brian was already a post-doc at the Rutherford-lab and a member of the TASSO collaboration.

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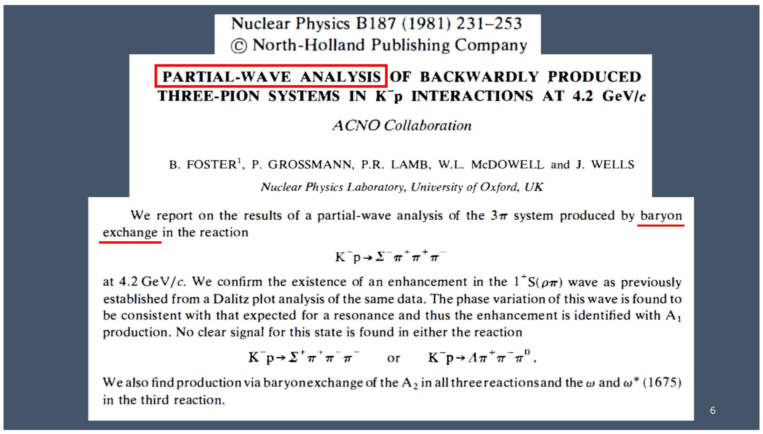

shows the title page of this paper: PARTIAL-WAVE ANALYSIS OF BACKWARDLY PRODUCED THREE-PION SYSTEMS IN K-p INTERACTIONS AT 4.2 GeV/c.

The subject of the paper is described in the Introduction as: 'The confusion surrounding the $J^P = 1^+$ mesons is one of the outstanding problems in the spectroscopy of elementary particles. Although the B and D mesons are well established and the spin-parity of the E meson has recently been shown to be 1^+[1], there is still much uncertainty about the Q-mesons [2] and particularly the A_1 [3]. Attempts to put these mesons in SU(3) nonets using the previously available information have not given a completely satisfactory answer (see for example

[4]).' End quote.

It illustrates the rich, or rather, the complex phenomenology of soft strong interactions that we were trying to makes sense of and the thinking was very much dominated by the representations of the group SU(3) of flavor.

The naming of these mesons has meanwhile been changed, D and B now refer to charm and beauty, but their spectroscopy has survived, as can be easily found out by inspecting the particle listings of the Particle Data group.

Two more remarks concerning this paper: it refers to baryon exchange, because the three pions are produced in the direction of the proton beam in the centre-of-mass system. The resonant spin-parity $1^+\rho\pi$ state was only observed when at the proton vertex an anti-neutron was absorbed, and not in reactions where an anti-Δ^{++} or an anti-proton was absorbed.

A second remark concerns a quotation of a former and later senior Oxford colleague of Brian, with whom Brian disagreed:

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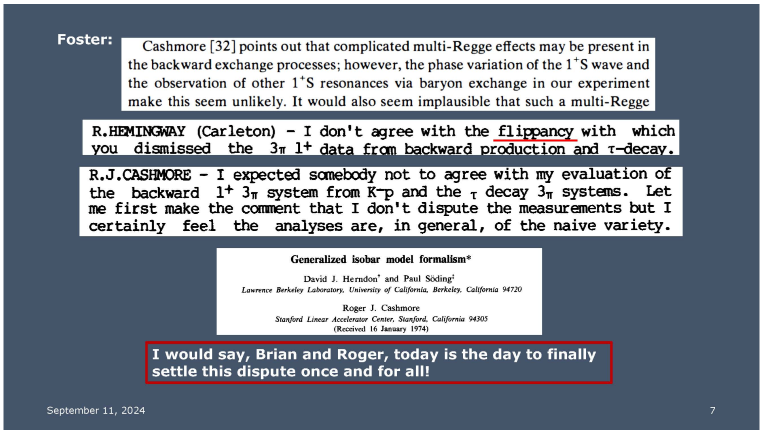
'Cashmore [32] points out that complicated multi-Regge effects may be present in the backward exchange processes; however, the phase variation of the 1 +s wave and the observation of other 1 +s



resonances via baryon exchange in our experiment make this seem unlikely.'

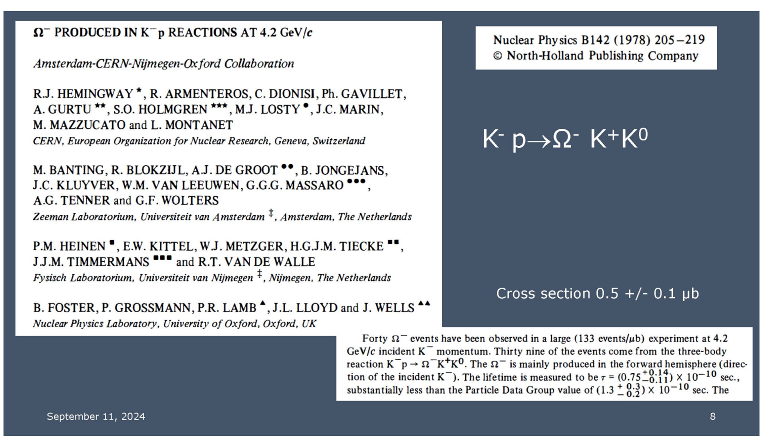
And also our ACNO colleague Richard Hemingway did not agree with Roger, I think. He accused Roger of 'flippancy' and although I don't know the word and could not find it in the dictionary, it does not sound as a very positive qualification! By the way, I had a brief correspondence with Richard on the old X42 days and he wrote: 'I'm always very happy to hear/read news items about my old colleagues (from long ago!). X42 was a delightful experiment and I was fortunate to have played a part. Many of the young scientists that participated in X42 went on to become senior people in the Institutes and ... enjoyed illustrious careers. I always felt proud to have known you all. When you talk to Brian at the symposium, please give him my very best wishes for a long retirement.' Hereby.

I would say, Brian and Roger, today is the day to finally settle this dispiute once and for all. This 'backward stuff', by the way, is the best cited of the ACNO papers and I still find it intriguing.

Incidently, in trying to understand the difference of opinion between Brian and Roger I found a paper published by Roger with two co-authors (Herndon and Söding) in 1973 on the partial wave decomposition of multiparticle hadron states, that is still amply cited today in the framework of the analysis of the decays of charm and beauty mesons. Remarkable!

Let us continue a little with X42 and discuss one of its flagship papers that Brian made considerable contributions to: Ω^- PRODUCED IN K-p REACTIONS AT 4.2 GeV/c.

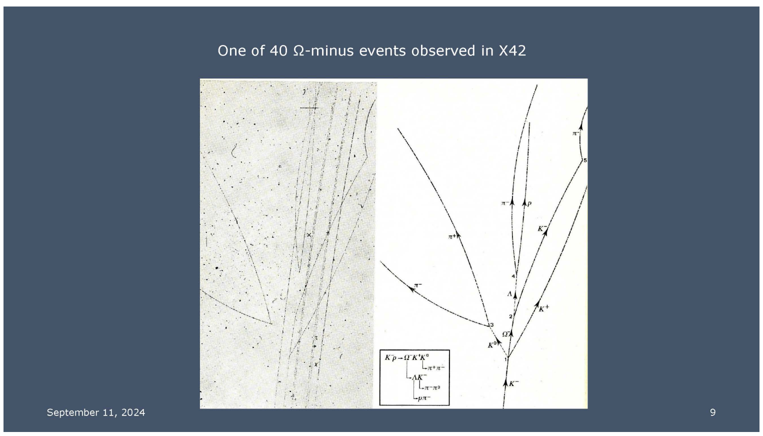
Slide 8



I am not an author of this paper because in Nijmegen I was not considered senior enough to sign such an important paper. The Ω^- was discovered in 1964 in Brookhaven, as already mentioned, in the same year that Gell-Mann and Zweig published the quark model.

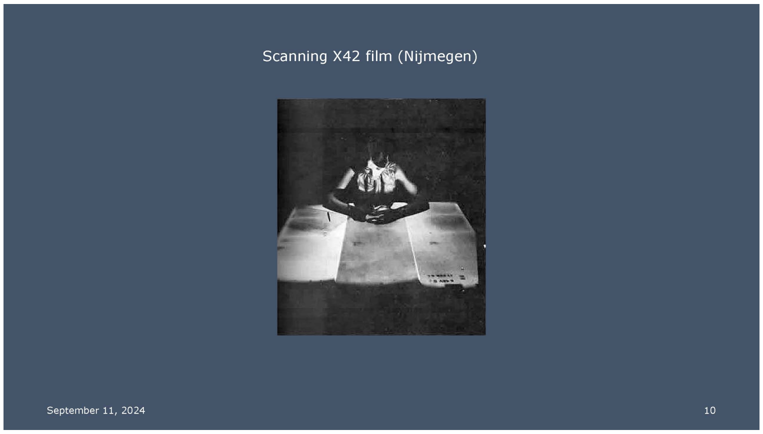
The X42 paper reported the study of 40 events and the mass, lifetime and decay asymmetry where measured.

Slide 9



This slide also gives me the opportunity to remind ourselves of the practical work involved in bubble chamber analysis. Scanning, **Slide 10**

twice and independently to determine efficiencies, and measurement, using devices such as ENETRA, and more advanced devices such as the HPD, Spiral Reader and, not to forget PEPR. And then the events were processed in a successive chain of programmes, REAP, THRESH and GRIND if I remember correctly. Finally a Data Sum-



mary Tape was produced, making the data available for analysis.

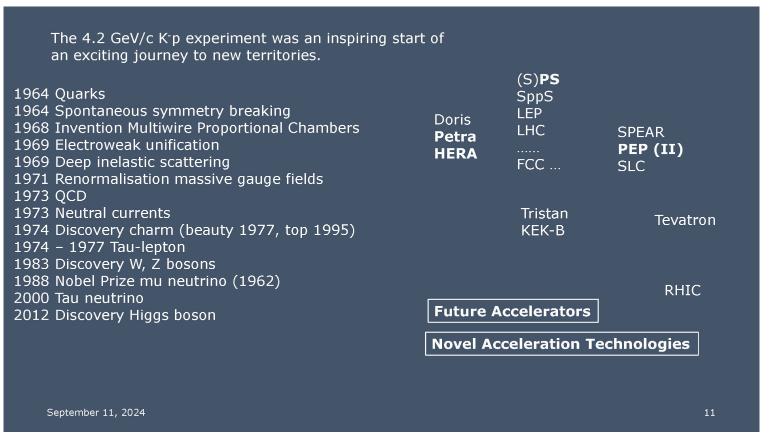
Our collaboration meetings, small by present day standards, where organized at CERN, in a relatively small meeting room in building 13, and also in Nijmegen, Amsterdam and here in Oxford.

The 4.2 GeV/c K-p experiment yielded a wealth of results on hadron resonances and production mechanisms, many of these results are still referenced in the Particle Data Tables.

As it happened, in the period up to 1978 when we worked hard to make sense of hadrons, their spectrocopy and production mechanisms, very important breakthroughs that would change the course of high energy physics took place. They would also change the course of Brian's research as will become clear during the following talks.

The discovery of deep inelastic scattering, the discovery of the J/ψ and open charm, the development of the electroweak standard model, the formulation of QCD would point the way to experiments at high energy electron-positron colliders, at an electron/positron proton collider, at proton-antiproton colliders and at the large hadron collider. For an incomplete overview see

Slide 11. On this slide I also indicate ‘Future Accelerators’ as an

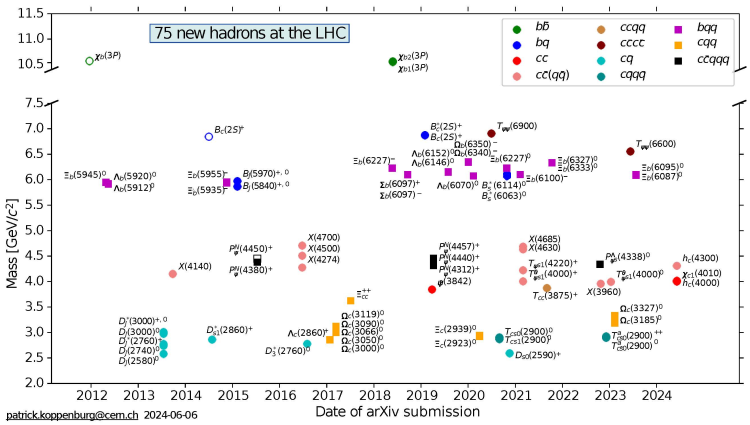


important area where informed decisions will have to be made soon. The future of CERN will depend on these. Finally I also indicated Novel Accelerator Technologies as an area of great interest also for Brian’s recent research activities.

But all this does not mean that the days of hadron spectroscopy are over!

Slide 12

shows an overview of 75 new hadrons that have been discovered at the LHC, the vast majority by LHCb. The overview is due to Patrick



Koppenburg from Nikhef.

Whether we will ever understand these spectra quantitatively I don't know. A fact is, that these recent and also our light quark spectra are part of Nature and studying the latter was a wonderful start for many of our generation in high energy physics, including Brian.

Optional:

Before finishing one final remark on a recent interaction I had with Brian. I had stumbled over a large number of publications on a new aggregation state of hydrogen: so called ultradense hydrogen. Manifest nonsense and nonsense is too mild a word. What puzzled and puzzles me is that 20, 30 or more of these papers, all by the same author, had been published in respectable journals, such as Physica Scripta published by the IOP. These papers invoke violation of baryon number, in particular proton-proton annihilation, as an infinite source of energy. Another detail is that the structure of ultradense hydrogen is incompatible with quantum mechanics. Thanks to Brian's encouragement my co-author and I got a comment published in Physica Scripta, whilst all other journals preferred to sweep their embarassing mistakes under the rug.

End optional.

Brian, congratulations on a wonderful career in high energy physics, thanks for your many contributions, for your leadership and for your friendship!

Thank you for your attention!